CLOUDSAT: PROFILING CLOUDS FROM SPACE

Steven J. Walter
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, CA 91109

INTRODUCTION

CloudSat is being proposed to measure the vertical structure of clouds from space. This mission is designed to investigate feedback mechanisms linking clouds and climate. Existing models relating cloudiness, atmospheric circulation, and temperature lack the accuracy needed to meet climate modeling needs. Current and planned observat ion systems will only passively sense the uppermost cloud layer and will usually be unable to observe the structure of underlying clouds. Measuring the vertical cloud profile requires a combination of active and passive instruments.

The CloudSat mission is being developed for the cost-con strained NASA Earth System Science Pathfinder (ESSP) mission series. The proposed payload consists of a 94-GHz cloud profiling radar (CPR), a dual-wavelength aerosol and cloud lidar (ACL), an oxygen A-band near-infrared spectrometer integrated with a visible imager (ABSI), and a submillimeter-wave cloud ice radiometer (CIR) as shown in Figure 1.

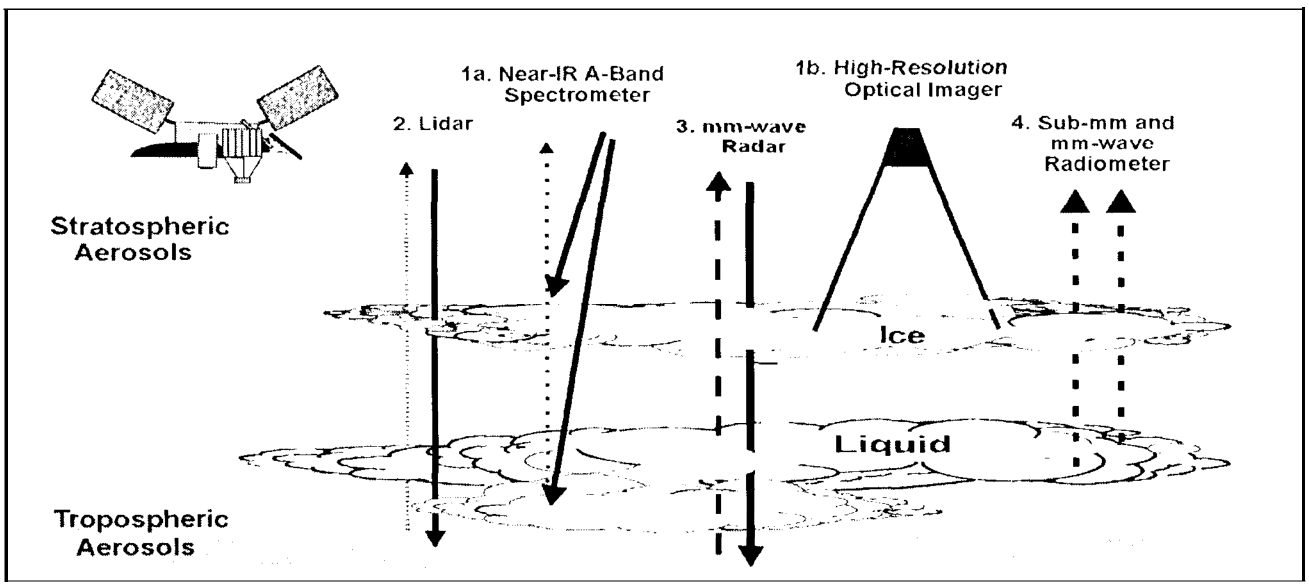

Figure 1. CloudSat retrieves vertical cloud profiles using a radar, lidar, and two passive sensors.

MISSION OBJECTIVES

CloudSat is designed to resolve the mechanisms relating radiation, climate, and clouds. It will compile a database of cloud measurements to identify and quantify fundamental climatic processes relating the Earth energy balance to its hydrological cycle. The ultimate goal is improve tbc accuracy of climate models by developing more realistic representations of clouds and their influence on climate. CloudSat will also demonstrates key technologies for operational space-based cloud profiling and will facilitate assessment of the value of cloud profiles for forecasting weather.

Understanding and resolving climate feedback mechanisms is an important objective for the NASA EOS mission set. However, planned EOS, GOES, and NPOESS payloads will not be able to reliably detect the presence of multi-layer clouds. They are therefore limited in their ability to characterize cloud-induced changes in radiative heating of the atmosphere. It is this observational gap that CloudSat intends to fill. The design for CloudSat will provide new insight into climatic processes by:

- Documenting the vertical distribution of cloud and aerosols with 250 to 500 meter resolution
- Retrieving the total cirrus ice content and vertical distribution of ice water.
- Measuring optical depth and cloud phase.
- Validating EOS cloud and radiative flux products.
- Integrating CloudSat and EOS observations to assess the performance of climate models.

MISSION PAYLOAD

Cloud Profiling Radar (CPR)

The CloudSat radar, CPR, will profile clouds. It will operates at 94-GHz using 1.5 kW peak transmit power, a repetition rate of 4700 Hz, and an uncoded pulse width of 3.3 μs. The radar footprint is roughly 900 meters requiring an antenna diameter of 1.85 meters. The antenna, a center-fed Cassegrain, requires that spacecraft be pointed with an accuracy of 0.5(' to minimize specular surface reflections and measurement contamination from sidelobe reflections.

The choice of radar frequencies is a trade-off between sensitivity, technological limitations, and atmospheric attenuation. Radar backscatter from hydrometeors (ice crystals, cloud droplets, and precipitation) increases dramatically with increasing frequency. The sensitivity to cloud particles needs to be balanced against atmospheric transmittance and the performance of radar technology which both degrade at higher frequencies. A small percentage of the time, the 94-Ghz radar will not be able to penetrate the cloud base. This will occur when very thick clouds or heavy precipitation are present. The mission objective dictates this choice. To derive radiative heating, it is more important to have the sensitivity to detect high this clouds than it is to determine the base of a heavy cloud deck.

The radar has been designed with pulse coding capability to enhance sensitivity to thin clouds in the mid- to upper-troposphere. When pulse coding is selected, the radar transmits 33.3 μs pulses at a 900 Hz repetition rate. Pulse coding increases sensitivity at the expense of generating range sidelobes from highly reflective clouds and the Earth surface. The surface-induced range sidelobes will obscure clouds near the ground. Thus, it is envisioned that coded pulses will be interspersed with uncoded pulses in order to resolve both thin clouds and sarfacc-level clouds.

Aerosol and Cloud Lidar (ACL)

ACL, is a dual-wavelength lidar for sensing thin clouds and aerosols. ACL was not part of the 1996 CloudSat proposal due to cost constraints; however, a lidar is planned for the proposal to be submitted in response to 1998 ESSP Announcement of Opportunity. The ACL, design parameters are less well defined than the other payload instruments due to the recent decision to reincorporate the ACL in next CloudSat proposal,. Two wavelengths are being considered for CloudSat (1064 nm and 532 mu). The power output will be determined by the radar sensitivity. The sensitivity of the lidar will be optimized for the regime where the radar will begin to lose sensitivity. It is expected that the lidar will be able to penetrate clouds with optical depths on the order of 1 to 2.

Oxygen A-Band Spectrometer and Visible Imager (ABSI)

ABSI is a high resolution spectrometer centered on the oxygen A-band (-770 nm) that is integrated with a visible imager. The spectrometer/imager will provide the capability of detecting thin clouds and aerosol layers, provide a coarse estimate of their altitude, determine optical depth, and document the morphology of the cloud field. With a signal-to-noise of 1000:1 it will be able to retrieve cloud properties to an optical depth of 0.02 with 3% accuracy. ABSI will only operate during the daytime because the spectrometer and imager require sunlight.

The visible imager *(748* nm ± *5 rim), provides* the context for CloudSat measurements. It will allow researchers to associate cloud profiles with mesoscale weather patterns. For example, it wilt be able to identify when a cloud profile is associated with a tropical storm, a cumulus column, or a uniform cloud deck. The data from the imager will be highly compressed to reduce its data requirements.

The high resolution spectrometer determines the optical depth and altitude of thin clouds by making high spectral resolution *(0.5* cm^{-1}) measurements at the oxygen A-band (761 nm -772 rim). The oxygen A-band is characterized by a "thicket" of closely spaced spectral lines. Therefore, a small change in wavelength will vary the rate at which light is attenuated as it traverses the atmosphere. With measurements made over a wide range of attenuation lengths, it is possible to determine optical depth, photon path length, various characteristics of the scattering particle, and the scattering altitude.

Cloud Ice Radiometer (CLIR)

Submillimeter-wave radiometric measurement of cloud ice is a new technique for retrieving cirrus ice mass and ice crystal size. It can be understood intuitively. In the absence of clouds, the Earth appears to emit a relatively uniform background of submillimeter-wave (> 300 GHz) radiation. The source of these emissions is mid- and lower-tropospheric water vapor. When viewed from space, cirrus clouds will scatter the background emissions back toward the Earth reducing the upward flux of submillimeter-wave energy. Hence, cirrus clouds appear "cool" against the "warm" emission background. The reduction in radiative brightness is dependent on both the number of ice crystals and their sizes. Measurements made at two widely separated frequencies permit variations in thermal flux caused by changes in mean crystal size to be distinguished from changes in ice content.

The CloudSat radiometer is a sensitive heterodyne receiver tuned to 640 GHz and 183 GHz. When coupled with 94 GHz radar measurements, the 640 GHz measurements of atmospheric brightness allows retrieval of ice mass and mean crystal size. Since 183 GHz is situated on a water vapor line, the frequency can be chosen to mimic the atmospheric opacity observed at 640 GHz. However, a radiometric measurement at 183 GHz has virtually no sensitivity to cloud ice. Therefore, measurements at 183 GHz provides an independent measure of variations in the water vapor emission background. This will ensure that the underlying emission structure will not contaminate the retrievals of ice mass and crystal size.

CALIBRATION

Independent calibration of the instrument payload will take advantage of misting ground-based observational sites. The DOE Cloud and Radiation Testbed in Oklahoma, Alaska, and the South Pacific will provide ground-based radars, lidars, and passive instrumentation for concurrent cloud measurements. Additionally, it is anticipated that CloudSat validation will be coordinated with the NASA airborne science campaigns. '1'here arc airborne versions of CPR, ACL, CLIR, and ABSI either under development or undergoing flight tests. These instruments combined with other airborne cloud sensors will provide the capability to verify the instrumental measurements and validate the cloud retrievals. Finally, there arc a series of university and governmental research facilities that will be made available for flight validation. Due to the importance of spacecraft validation, several members of the CloudSat science team have been chosen to coordinate a range of ground-based validation activities.

SPACECRAFT REQUIREMENTS

The mission is designed for a two-year lifetime as specified by the NASA ESSP solicitation. This will enable CloudSat to observe more than one seasonal cycle. The desired orbit is a nearly sun-synchronous orbit (altitude = -475 *km,* inclination = 97.1°) providing coverage to 83° latitude. Communications is accomplished via an S-band transceiver using an omni-directional antenna and X-band transmitter utilizing a helical antenna. The total weight of the commercial spacecraft and payload is estimated to be approximately 600 kg requiring an average of 550 W of power.

CONCLUSIONS

CloudSat is being developed to measure the vertical structure of clouds from space. It integrates a cloud profiling radar and aerosol and cloud lidar with an A-band spectrometer/visible imager and a submillimeter-wave cloud ice radiometer. This payload is designed to profile clouds with 250 to 500 meter resolution, detect very thin clouds, image the regional cloud field, and retrieve cirrus ice content and crystal size, measure cloud optical depth, retrieve cirrus ice content, and assist in validating measurements made by the NASA Earth Observing System (110 S). CloudSat will also furnish an important technology demonstration for future scientific, civilian, and tactical forecast systems.

The CloudSat concept was originally proposed to the 1996 NASA ESSP mission opportunity. It was ranked very highly, but was not selected due to the ESSP program cost cap. Wc plan to propose this mission concept to the 1998 ESSP Announcement of Opportunity. The science team is currently exploring the possibility of teaming with international partners and other government agencies that have related interests to facilitate cost-sharing thereby improving the overall competitiveness of the proposal.

ACKNOWLEDGMENTS

This research was partially carried out by the Jet Propulsion Laboratory, California Institute of Technology, under a contract with National Aeronautics and Space Administration.